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Information Thermodynamics of Plasma Turbulence

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We propose a scheme to extract work from (plasma) turbulence without any energy cost using information thermodynamics. The results of verification of this concept by means of a numerical simulation are presented.

Information thermodynamics considers information and thermodynamic functions in the common framework of thermodynamics, enabling to decrease entropy using information (i.e. exchange between thermodynamic entropy and information entropy) without any energy cost. Historically, the pursuit of this idea was initiated by J. C. Maxwell, who considered a gedankenexperiment, in which a thermodynamic system immersed in a heat bath extracts work from the heat bath with manipulation of the system by an external intelligence called Maxwell daemon. With appropriate usage of information, perpetual heat engines of the second kind can be realized [1].

Turbulence is an energy-rich state sustained by steady energy injection. However, the stored energy in turbulence cannot be extracted as work, but rather dissipated as heat. This is analogous to the prohibition of perpetual heat engines of the second kind referred to as the second law of thermodynamics. Nevertheless, extracting coherent work from turbulence may be possible with the use of information on turbulence and thermodynamics. This study aims at the establishment and verification of theory of information thermodynamics of plasma wave turbulence employing numerical experiments.

The developed numerical code simulates one-dimensional wave turbulence and traces the motion of a particle in the turbulence with a periodic boundary condition. The particle is driven by the electrostatic field of the wave turbulence. We examined Kuramoto-Sivashinsky (K-S) turbulence as an example. The phase of the wave turbulence is manipulated according to a protocol based on the outcome of measurement of the particle in the phase space with no energy cost. Our model considered in this study, a single particle-turbulence system, is a non-equilibrium counterpart of the Szilard engine using a single particle fluctuating system in equilibrium thermodynamics [1].

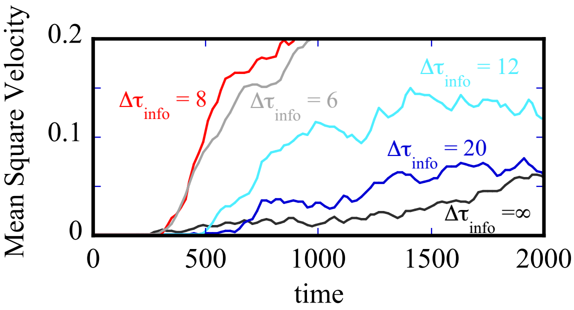

Fig. 1. Time evolution of mean squared velocity of the particle in the K-S turbulence for various values of $\Delta\tau_{\rm info}$. The case of no feedback control corresponds to $\Delta\tau_{\rm info} = \infty$, whose mean squared velocity $\propto$ *time*, indicating a normal diffusion in the velocity space (quasi-linear diffusion). For $\Delta\tau_{\rm info} < \infty$, however, development of the mean squared velocity faster than the normal diffusion can be seen.

Figure 1 shows time evolution of mean squared velocity of the particle in the K-S turbulence for various values of $\Delta\tau_{\rm info}$, where $\Delta\tau_{\rm info}$ is the time interval of the information acquisition of the particle in the phase space. The case of no feedback control corresponds to $\Delta\tau_{\rm info} = \infty$. When no feedback control is applied, the mean squared velocity $\propto$ *time*, indicating diffusion in the velocity space (so-called quasi-linear diffusion). For $\Delta\tau_{\rm info} < \infty$, on the other hand, development of the mean squared velocity faster than the normal diffusion can be seen. The shorter $\Delta\tau_{\rm info}$ is, the faster and the higher the acceleration rate and the achievable final velocities are. The transition of the increasing rate of the mean squared velocity for $\Delta\tau_{\rm info}$ is considered to be a critical phenomenon (second-order phase transition, continuous transition).

While our protocol is for a single particle-turbulence system, it can be shown that the scheme can be applied into many-particle systems with macroscopic measurements if spontaneous symmetry breaking is expected in the many-particle system.

References

[1] Parrondo, et al., Nature Physics, (2015).